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Ocean acidification needs more publicity as part of a strategy to avoid a global decline in calcifier populations

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Ocean acidification (OA) is caused by increasing atmospheric concentrations of carbon dioxide, which dissolves in seawater to produce carbonic acid. This carbonic acid reduces the availability of dissolved aragonite needed for production of some invertebrate exoskeletons with potentially severe consequences for marine calcifier populations. There is a lack of public information on OA with less than 1% of press coverage on OA compared with climate change; OA is not included in UK GCSE and A Level specifications and textbooks; environmental campaigners are much less active in campaigning about OA compared with climate change. As a result of the lack of public awareness OA is rarely discussed in the UK Parliament. Much more public education about OA is needed so that people can respond to the urgent need for technological and lifestyle changes needed to massively reduce carbon dioxide emissions.

Keywords: Ocean acidification, carbon dioxide, aragonite, calcifier, education

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Another milestone in human impacts on the Earth occurred in 2015 when mean annual atmospheric carbon dioxide concentrations first exceeded 400 ppm (Tans & Keeling, 2016). Ice core data indicate that atmospheric carbon dioxide concentrations are now more than 100 ppm higher than at any time during the past 800,000 years (Stap *et al.*, 2014). About a third to a half of anthropogenically derived carbon dioxide dissolves in seawater to form carbonic acid, a process called ocean acidification (OA). OA has caused seawater pH to decrease by 0.1 pH units between the pre-industrial period and the present, with predicted changes by the end of the current century of up to 0.5 pH units (Royal Society, 2005; Doney *et al.*, 2009).

Aragonite is a form of calcium carbonate used by many marine invertebrates in their shell or exoskeleton. If seawater is saturated or supersaturated with aragonite it is relatively easy for invertebrates to precipitate aragonite, but if seawater is unsaturated with aragonite there are at best increased metabolic costs in maintaining an exoskeleton (Wood *et al.*, 2008) and at worst dissolution can be corrosive. Unfortunately, OA reduces the concentration of aragonite dissolved in seawater and can cause seawater to become unsaturated with aragonite.

Colder seawater contains less dissolved aragonite and so is likely to become undersaturated with respect to aragonite at lower atmospheric carbon dioxide concentrations, so organisms living in polar waters are more vulnerable to the effects of OA. The potential scale and speed of these changes is large – undersaturation with aragonite is predicted to occur in some Arctic waters intermittently by 2016, permanently by 2029 and the entire water column by 2090 (Steinacher *et al.*, 2009). Predictions for the Southern Ocean are aragonite undersaturation events starting about 2030, 30% of surface waters affected by 2060 and more than 70% by 2100 (Hauri *et al.*, 2016). Orr *et al.* (2005) predicted a greater effect with the entire Southern Ocean and subarctic Pacific Ocean being undersaturated by 2100. The duration of undersaturation events is also predicted to increase up to 6 months (Hauri *et al.*, 2016) and this might be especially harmful to organisms that might survive a few weeks of an inadequate aragonite supply.

Deeper waters tend to be undersaturated with aragonite and shallower waters tend to be saturated. The aragonite saturation horizon is the separation of these two saturation states and this horizon is expected to shoal, or become shallower, with increasing acidification. The shoaling rate can be fast, with a rate of 1.8 m $year^{-1}$ reported from the north-east Pacific (Chu *et al.*, 2016), which could result in the water surrounding a long-lived sessile organism, living close to the aragonite saturation horizon, changing from saturated to unsaturated with aragonite over a few years and potentially killing that organism. Also, species that are subject to upwelling of deeper water are likely to be vulnerable to OA, when the upwelling water combines with anthropogenic carbon dioxide (Feely *et al.*, 2008).

Therefore, OA reduces the area, depth and hence volume of seawater that is saturated with aragonite – a predicted reduction from 42% to 25% of the global seawater volume over the current century (Steinacher *et al.*, 2009). This has the potential to be a huge habitat loss for calcifiers and may be an

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underestimate of habitat loss as coral calcification rates start to decrease as seawater falls below 300% saturation with aragonite (Gattuso *et al*., 1998), and seawater at or above this saturation is predicted to completely disappear by 2070, or about 630 ppm of atmospheric carbon dioxide (Steinacher *et al*., 2009).

A considerable range of taxonomic groups are vulnerable to the effects of OA including echinoderms (Dupont *et al*., 2010), corals, coralline algae, molluscs and foraminifera (Kuffner *et al*., 2008). The response of different species to OA can be complex, more species appear to be negatively affected (Doney *et al*., 2009; Kroeker *et al*., 2010), however some photosynthesizing species might benefit from the increased availability of carbon dioxide (Iglesias-Rodriguez *et al*., 2008). With so many groups of organisms affected there is potential for disruption of food webs, commercial fisheries, ecotourism and in the case of corals a reduction in storm protection to human coastal communities.

OA is not just a problem for the future. The change from pre-industrial to present day atmospheric carbon dioxide concentrations is already causing a doubling of the incidence of severe shell dissolution of the pteropod, *Limacina helicina*, living in upwelling water off the Californian coast (Bednaršek *et al*., 2014) and may have caused the shells of the bivalve *Mercenaria mercenaria* to decrease in diameter by over 40% and decrease in thickness by over 60% (Talmage & Gobler, 2010). A reduction in shell thickness could increase predation risk (Bibby *et al*., 2007).

Predicting from laboratory and desk studies to whole oceans several decades into the future should always be done with caution. However, it seems we are on a pathway to considerable global losses of calcifiers – and this process is happening rapidly, leaving little time to do anything about it. The only way to stop the increasing ecological damage caused by OA is to stop atmospheric carbon dioxide concentrations increasing as soon as possible – and these cuts to emissions need to be much deeper and much sooner than the cuts proposed for climate change mitigation. With some species already affected by OA and Arctic waters already becoming unsaturated with aragonite, the societal timescale for stabilization of atmospheric carbon dioxide is a few years, not decades or centuries.

The upward trending graphs of carbon dioxide at Mauna Loa (Tans & Keeling, 2016) suggest that stopping atmospheric carbon dioxide from increasing is impossible. The word impossible has two responses – give up and accept the inevitable ocean scale damage – or see it as a challenge, and part of achieving that challenge means effective public education, so that people can understand and respond to the urgent need for the technological and lifestyle changes needed to massively reduce carbon dioxide emissions.

Unfortunately public education on OA lags well behind public education on climate change. A search of the Reuters website (Reuters, 2016) for 'ocean acidification' produced 122 stories, whereas a search for 'climate change' resulted in 18,400 stories, so there are only about 0.7% of articles on ocean acidification compared with climate change. A similar percentage was found on the British Broadcasting Corporation website in 2013 (Westgarth-Smith, 2013).

UK school examination boards make no mention of OA at GCSE, or A Level Biology, although some of the specifications include the carbon cycle, carbon sequestration in oceans as a way of removing carbon dioxide from the atmosphere and acid gas pollution (AQA, 2012, 2015, 2016; Edexcel, 2014), it is likely that acid gas pollution will be interpreted by teachers as acid rain caused by sulphur dioxide and oxides of nitrogen rather than carbon dioxide. OA is also not mentioned in the specifications for International GCSE and the International A Level in Biology (Cambridge International Examinations, 2014a, b). Teachers have some freedom in how they present a topic, so it is possible that OA is taught in some schools and colleges.

A search of GCSE, A Level and undergraduate Biology, Chemistry and Geography textbooks in a large bookshop in west London produced no references to OA. Perhaps more worryingly a book on environmental law and another on climate change also did not mention OA.

A search of Google Images for 'climate change protest' produced many images of placards and banners used on protests – many were imaginative slogans however a search for 'ocean acidification protest' produced very few images. So despite the skill and dedication of the protestors they appear to have very limited awareness of ocean acidification, although ultimately any achievement climate change campaigners make in carbon dioxide emissions reduction might help mitigate OA. There is some, limited, evidence that environmental campaigning organizations are trying to increase awareness of OA (Greenpeace International, 2016).

Hansard Online is a record of the proceedings of the UK House of Commons and House of Lords. Hansard records for climate change: 116 debate titles, 7159 spoken references and 354 written statements whereas for ocean acidification there were no debates or written statements and only eight spoken references. It seems therefore that British politics has a negligible role in dealing with OA and this is likely to remain the situation until the electorate are better informed on this topic. Ultimately, as a scientific community, if we want to influence government decision making to reduce the problem of OA we may first have to educate the electorate, and with OA already causing ecological damage we need to do this quickly. Carbon dioxide emissions come from all countries, so information needs disseminating to people in all countries.

In conclusion, OA is already causing harm to calcifiers, and unless atmospheric carbon dioxide concentrations stop increasing soon, the world is on a path to a significant impoverishment of marine calcifying organisms. There is a real lack of information flow to the public and without this information there will be no political motivation for the urgent policy changes needed to stop atmospheric carbon dioxide concentrations increasing and hence control OA. So, when next you publish a paper on ocean acidification, please take the time to write a press release – that will be one small step to increase public knowledge about OA.

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